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MODERN HEARING AID FITTING

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First let me thank you for the opportunity of coming to talk to you about hearing aids and audiology. Your job as rehabilitation counselors, working with the deaf and hard of hearing entails so much more than mine but in many cases the fitting of the hearing aid, the measuring of the hearing loss and the counseling which I do regarding the use of amplification and language is critical to your job. Indeed it often may result in your failing to accomplish your job as well as it should be accomplished. It has been my experience during the last thirty years that by and large rehabilitation of the deaf and hard of hearing precedes rather well often in spite of very poor hearing aid fitting and audiological counseling. Although my field of audiology has made great strides in diagnostic test procedures in many other areas. Audiological information generally has not been applied to the hearing aid field. In fact, the audiologist has in the past tended to draw away from hearing aids and to leave them more to the commercial interests. This situation has been changing very rapidly in the past few years and more and more audiologists are coming into the field of hearing aids, more and more research has been done on hearing aids, and more and more is being learned about the fitting and utilization of the newer developments in the hearing aid field. My own work for the past few years has been primarily in the area of developing newer and we hope better methods for fitting the hearing aids. It should go without saying that the more I know about your clients, the more you know about the modern hearing aid, and the modern fitting procedures, the better we can work together to improve the loss of that client. Therefore during the time allotted, I will try to give you a picture of some of the newer developments in hearing aids and in the fitting procedures.

The three most important developments in recent years which contribute to better hearing aid fitting may be broken down as first; the newer and versatile hearing aids which offer fitting possibilities that we never dreamed of thirty years ago. We will talk more about this and impedance audiometry which you may not have heard about, specifically the discovery that stapedial reflex is intimately associated with the beginning of loudness discomfort and thirdly; reasonably priced hearing aid analyzers with which we can check and adjust the parameters we want in order to match the hearing aid to the patient and finally, we are developing methods for applying our knowledge of hearing function and our newly developed equipment in the proper selection of the hearing aid for the particular patient.

First, let's look at human hearing as it relates to normal speech. The first slides show sound pressure level for intensity of sound as measured against frequency of sound, frequency going across and increasing sound pressure level starting at the bottom at the zero and going to 140 decibels. Sound is measured in sound pressure level and the engineer depicts it with a graph like this. The curved line going across the bottom is the normal human threshold of hearing for each of the several frequencies shown. Starting at the left side, we show 250 cycles going on over to 4000 cycles, the higher tone. The lower tones around 500 to 1000 cycles are most important for hearing and understanding of vowel sounds. From 1000 upward, mostly 1000 to 2000 cycles; these are your consonant sounds. The vowel sounds in the English language carry primarily the melody and the sensation of loudness while the consonant sounds carry approximately 95% of the meaning of speech; so the consonant sound is extremely important for understanding speech. The line which you see at approximately 95 decibels depicts what we call the loudness discomfort level for the normal ear. These data have been developed through measuring the reflex contraction of the tiny muscle which is connected to the third of the little middle ear bones, the stapes or stirrup bones. This small muscle contracts automatically whenever a loud sound reaches the ear, apparently, in order to tighten up this system and protect the inner ear from damage. The level at which this contraction occurs, is measured by the impedance meter which we find in all audiological clinics and laboratories. In fact, the measurement is a part of almost all audiological evaluations. We call this the loudness discomfort level because McCandless and his research group at the University of Utah Medical Center have shown that the stapedial research threshold is very, very close to the beginning of discomfort in both the normal ear and the ear with a sensorineural type of hearing loss. A dotted line crossing the graph at about 60 decibels is marked speech. This shows the intensity levels of the various frequency ranges within normal speech. That is, if I am talking to you now at a normal level, the lower frequencies, the vowel sounds will be reaching you at approximately 60 to 62 decibels while a higher frequency will drop down 15 to 20 decibels lower than that; the consonant sounds not being as strong as the vowels. There should be one further line on the graph up at approximately 135 decibels right up close to the top. This level may be described as the danger level. At approximately 135 decibels, sound pressure level, we reach a point where the pressure is so intense that it may cause physical damage to the ear. Even an extremely brief exposure as low as 90 decibels may cause hearing loss after years of exposure but at 135 decibels there is danger of immediate damage. These levels are reflected in the Occupational Safety and Hazards Act which limits a worker's allowable noise exposure to 8 hours a day at 90 decibels and will not allow for any exposure at all at 135 decibels unless the worker is wearing earplugs or earmuffs. Therefore under no circumstances should a hearing aid deliver more than 135 decibels sound pressure level to an ear for fear of sustaining organic damage. It is an unfortunate fact of life that the threshold of hearing may shift upward to any degree without concomitant shift in the loudness discomfort level for the danger level for noise exposure. In fact, it is quite common to see a patient who has sustained a very severe hearing loss but who becomes uncomfortable even at lower voice levels than the normal ear. This of course, results in a very narrow range of loudness over which he can receive comfortable listening. It has been estimated that 80 to 95% of the hearing aids which have been bought and then relegated to a dresser drawer, not used, have been rejected because they allowed the sound to become uncomfortably loud. It's most distressing to try to listen and understand speech when each vowel sound is pronounced too loudly and every time a door is slammed, one jumps, and everytime a plate is put on a table, it causes a clashing sound. We also have some indication that when we reach this level of discomfort, sounds become distorted so it's impossible or extremely difficult to understand speech when the louder portions of speech are reaching an uncomfortable level which cause the stapedial reflex to come into action.

All of these things must be considered in fitting a hearing aid and measures must be carefully made to assure that we give the best possible reproduction of sound through our mechanical devices that we can. With this knowledge, we can set certain limits on our hearing aid. First, we know that since normal speech is the signal that we most desire to hear, we want the hearing aid to raise this signal to somewhere within the usable range; that is somewhere between the patient's threshold of hearing and his threshold of discomfort or loudness discomfort level as we have measured it. We feel intuitively and with some assurance from looking at the normal relationships between thresholds, normal speech and loudness discomfort level, that the patient with a hearing loss should also hear normal at approximately halfway between his threshold of hearing and his threshold of discomfort. This gives us a goal to aim for in a decision as to how much gain or amplification the hearing aid should give us. Of course, we have discussed the various frequencies involved in listening to speech, then we will have come as close as possible to reaching the ideal hearing aid fitting as we see it today.

Now let me talk for a while about my own procedure for fitting hearing aids which I have developed over a number of years. This involves an instrument which I call the Bragg SPL Converter and which you saw a part of on slide #2. Unfortunately, the audiometer with which we measure hearing, is not calibrated in terms of normal hearing to hearing level, while the hearing aid is calibrated in sound pressure level. It's therefore necessary in order to envision and measure the requirements of amplification that we convert one set of findings so that they correspond to the other. So we have developed a simple converter which does this job. Let us go back to the slide which shows the normal threshold of discomfort for hearing as it relates to normal speech and a normal threshold of discomfort or loudness discomfort level. This as I said is part of the SPL Converter. And we point out again that the normal relationship is with average speech falling somewhere near halfway between the threshold of hearing and the threshold of discomfort or loudness discomfort level. Now let us look at the next slide which shows audiometric data with the audiogram lines bent in order that we may superimpose them over the pressure data chart which we just showed in such a way that it will convert the recorded data into sound pressure level, that is, we have only to record the patient's threshold and his stapedial reflect thresholds and swing the data over to the other graph where we can read them in sound pressure level and see them in relations to normal speech, normal threshold, and normal stapedial reflexes. Once we have done this, we have a picture then of the patient's hearing in relations to normal hearing and we can measure at each frequency to determine how many decibels of amplification are required to bring that portion of speech up to the desired listening level or to one half the distance between the patient's threshold of hearing and his threshold of stapedial reflex. At the same time, we have recorded his stapedial reflex in sound pressure level and we are able to adjust or select a hearing aid which will not exceed that level under any circumstances. It is at this point that the modern hearing aid analyzer becomes important. The hearing aid analyzer is an instrument which can now be afforded by any audiology clinic and which measures the parameters of performance for a hearing aid. The hearing aid is simply inserted into the hearing aid test box and adjusted for the desired performance. The test box allows the various test zones to be presented at whatever level is desired and it reads out the number of decibels of output of the hearing aid. Thus we can adjust the hearing aid so that it gives us the desired gain at each of the test frequencies and at the same time we can adjust the limit on it so that it does not exceed the patient's loudness discomfort level. The converter also provides a graphic representation of the relationships among speech and the hearing factors and help in explaining to the patient or the family about the need for amplification and the limitations of a hearing aid in the patient's particular case. One further advantage we have found in using the SPL Converter, is in checking the efficiency of the hearing aid and the correctness of its fitting. Since the converter gives us the desired amplification at each frequency, it is a simple matter to subtract that much amplification from the patient's hearing loss at that frequency to determine what his aided threshold should be for each test tone. We then place the patient in front of the loudspeaker with his hearing aid on and carry out an aided sound field test for the various test frequencies. In this way we can determine if the hearing aid is performing in the ear as it was expected to do.

For example, if we have determined that the client requires 28 decibels of amplification at 2000 cycles in order to bring 2000 cycles to the effects of allowing the amplification to go beyond the loudness discomfort level of the patient and this rule establishes the maximum power or saturation sound pressure level as it is called in our hearing aids. One third parameter which describes the desired hearing aid is frequency response which may be established if we establish the required amplification at the various frequencies. So we may say that the hearing aid which should give the patient the best possible hearing for normal speech is the one which will first, never become distressingly loud regardless of the input signal. Secondly, one which will amplify each of the frequency ranges in speech to a level somewhere approximately halfway between the patient's threshold of hearing and his threshold of discomfort. Of course, other factors such as distortion, comfort of wearing, ease of controlling, price, and cosmetics, should also be considered.

Now let's look at some of the modern hearing aids and see what the engineer gives us to work with. The first slide shows the specifications for the Norelco type HP 8146 hearing aid. This is a body type aid; that is the patient wears the amplifier and microphone in his pocket or in a strap on his chest and the wire comes up to the ear with a receiver or loudspeaker fitting in the ear. Notice that the maximum power output of this hearing aid can be brought up to as much as 140 decibels. For 11 decibels greater than that which we decided was dangerous to the hearing mechanisms, maximum amplification is 92 decibels. Now let's look at the next slide which shows a very powerful behind-the-ear hearing aid and we see that maximum power output in this aid is 137 decibels with gain or maximum amplification up to 67 decibels. From this we can see that even using the behind-the-ear aid; and this is not the most powerful one on the market, we can reach levels which we don't need to reach, that is levels which are dangerous to the structure of the hearing mechanism and may result in additional damage to the inner ear. Therefore we are in no need of greater power than we have at the present time even in the behind-the-ear hearing aid. I may add parenthetically here, that I personally seldom fit the body aid because the behind-the-ear aid is so much smaller and still has as much or more power than I need. I do use the body aid for very small children and for the elder people who may have difficulty with holding and handling the controls of the behind-the-ear hearing aid. But it is my opinion that the behind-the-ear can provide the acoustical responses which we need in almost all cases. The greatest exception is in that case where a blockage or conductive loss impedes passage of sound through to the inner ear and we must overcome that before we can get sound pressure into the inner ear. The most important aspect of these powerful hearing aids, however, is that they are provided with controllable maximum power so that we are able to utilize as much power as we like but through a screwdriver adjustment, we can limit what is available to the patient which brings us to the next and perhaps the most important modern development in hearing aids which is the power limiter or the compression circuit or the automatic gain control. All of these give us various degrees of control over the relationship between the amplification and the maximum power output.

Let me explain briefly how compression works. Consider the patient, if you will, who has a hearing loss of 75 decibels and a comfortable listening level of approximately 80 decibels but whose loudness discomfort level is 90 decibels, this patient has a very narrow range of comfortable listening as far as loudness is concerned. At 80 decibels things are comfortable and clear, at 90 decibels they become uncomfortable and distorted. Now when we consider that certain vowel sounds in the English language are as much as 28 decibels louder than consonant sounds, the patient has a great difficulty in listening to amplified speech. That is, if we amplify the consonants enough so that he can hear them at approximately 80 decibels or comfortably loud, then the vowel sounds may go as loud as 108 decibels which greatly exceeds this patient's level of discomfort. Therefore he gets not only uncomfortable listening but the vowel sounds may be so loud even as to drown out the consonant sounds so that he hears but doesn't understand. We have all heard of old grandpa who says, "Speak up young man," and when some one talks a little louder he says, "Young man you don't have to yell at me, I can hear fine." By using the proper compression circuit, we are now able to compress that varying sound into grandpa's comfortable listening level. For example, we can give him a hearing aid which will allow him to set the comfortable level with his volume control, then when any louder sound comes into the microphone, the instrument automatically turns itself down as long as that sound is on in order to keep it within whatever comfortable range we have set. This action takes place within thousands of seconds so that the instrument can literally turn itself down for the louder vowel sounds and back up immediately in time to catch the very weak consonant sounds, thus reversing grandpa's distorted loudness function and returning sounds to their more normal loudness relationships such as you and I hear.

The next slide depicts how we can take advantage of sophisticated hearing aid circuits, that of the Norelco HP 8274 which has a variable compression. Note, on the vertical scale they show various limiter settings from 1 to 5 and across CF settings from 7 down to 2, the CF is the compression factor. That means roughly that once we set a particular level, any sound louder than that is automatically shut down by a ratio of 7 to 1. So that if grandpa sets his hearing aid for comfortable listening then any shout or loud sound which impinges on the microphone instead of being amplified to the same degree as normal speech, will be amplified perhaps only 1/7 as much. You can see that with this information we can adjust the hearing aid for any degree of loudness distortion and lowered loudness discomfort level. For example, take the very center graph which is a limiter setting of 3 and the CF or compression factor setting of 4. This means that the limiter is set with one screwdriver adjustment to 118 decibels if that is the maximum comfortable loudness which the patient can stand or the threshold of the stapedial reflex. If we have determined that he should be listening to normal speech which is 60 decibels at 110 decible level then this setting amplifies 60 decibels to 110 decibels or by a factor of 50 decibels and the maximum input of 90 decibels is only amplified to 118 or by 28 decibels. These controls allow the audiologist to prescribe a hearing aid which will help the patient who only a few years ago we would simply not have been able to give usable comfortable hearing. Even more sophisticated circuitry on other hearing aids allows the patient to set his own level of maximum power at the same time adjusting the comfort level to suit the particular situation in which he finds himself, whether it be the quiet of a doctor's office or the noise of a baseball game or discotheque. Another extremely helpful improvement has been the development of the high frequency emphasis hearing aid. Many many patients as a result of high fevers or certain drugs, such as streptomycin or noise exposure, lose hearing in the critical high frequency areas while retaining normal hearing in the low frequencies. This means that they hear the vowel sounds normally but are unable to hear the consonant sounds and therefore are unable to understand speech. They often say, "I can hear you but I can't understand," especially when there is a noisy background which drowns out high frequencies more. Until a few years ago and the development of the high frequency emphasis hearing aid, we could not help these patients because in order to amplify the high frequency consonant sounds enough for them to understand speech, it was necessary that we amplify the low frequencies so that the vowel sounds were either too loud for them to bear or were so loud that they drowned out the much weaker but more important consonant sounds. Now it is possible literally to bring up the consonant sounds without amplifying the low frequency vowel sounds at all. This has been made possible through the develoment of specialized circuitry and also through the discovery that we can allow the low frequency sounds to escape without amplification by venting the earmold or by leaving the ear open and simply bringing the high frequency sounds in through a piece of tubing from the hearing aid.

The low frequencies being omnidirectional tends to disperse through the opening while the directional high frequency sounds are led directly to the eardrum and amplified. One last development which has been helpful is the directional microphone. The hearing aid with the directional microphone amplifies those sounds which originate in front of the wearer by as much as 30 decibels more than those originated behind. This tends to eliminate the problem which the hearing aid user often has of hearing other sounds more loudly than the voice which he is trying to listen. The overall reduction in background noise may only be on the order of 10 decibels but this is crucial in the case of a sensorineural hearing loss since we know that the hearing loss of this kind causes an extreme problem in listening in background noises. Although a great deal of research needs to be done, we are learning more and more about the advantages of two hearing aids over one and in what instances it is worthwhile to fit two ears.

Now let us talk some more about the selection of hearing aids and how they are selected. Most hearing aid dealers and audiologists in one way or another classify hearing aids as mild, moderate, strong, high powered and so forth. Based on the audiogram or the speech threshold then, they classify the patient as either having a mild hearing loss or moderate hearing loss, or severe or profound loss. In most cases the patient with a moderate hearing loss is fitted with a moderately powered hearing aid, and the person with the severe hearing loss is tested only with the strong or high powered hearing aids. It has been unfortunate that the manufacturer of hearing aids, until recently, has been required to produce a hearing aid with a fixed relationship between the amount of gain and the amount of maximum power available. For example, a strong hearing aid or one which we would ordinarily use with a severe hearing loss case, would be set with a maximum power of 125 to 130 decibels. This means that the patient with a severe hearing loss of say 70 decibels would be provided with a hearing aid having some 50 decibels of gain and a maximum power of at least 125 decibels. The gain or amplification would be adjustable by the patient through his volume control wheel but the 125 to 130 decibel maximum power is built into the hearing aid as we discussed befôre a majority of the patient with this type of hearing loss still cannot tolerate a sound pressure level of more than 90 to 100 decibels. With this hearing aid they would be exposed to as much as 30 or 40 decibels more sound pressure than they could tolerate. If someone shouted close to them, a door was slammed or a truck went by, these are the reasons for distorted hearing aids. The fitter also tries to adjust the frequency response to the user's hearing loss by giving him high frequency hearing emphasis if his hearing loss is greater there and low frequency emphasis if he has sustained greater loss in the low tones. It may be stated unequivocally that there is no direct and necessary relationship between the threshold audiogram and the hearing aid specifications. The best amplification depends on the relationship between the incoming speech and the patient's own desired listening level which in turn depends most directly upon his level of discomfort. Simply stated, we must raise normal speech to a comfortable listening level for the patient without allowing even loud speech or extraneous loud noises to exceed the level of discomfort.

If we can reach these goals for all of the desired listening levels and we have learned that he has a 38 decibel hearing loss, then we would expect for him to have an aided threshold of 10 decibels by testing him in the sound field and recording the aided threshold, we can determine whether the hearing aid is providing too much or too little amplification at that frequency and that all the other frequencies we can then adjust the hearing aid or select a new one which performs better in that regard. The most satisfactory fitting will be accomplished with the hearing aid which most nearly achieves the desired listening level and at the same time which under no circumstances exceeds the loudness discomfort level for the patient.

And now I believe that my time is up. I would like to thank you for your attention. If there are further questions, I would be glad to talk after the sessions and I would like to point out that the fitting procedure which I have described and developed through the years, is dependent upon information gained from many many scientists working in the area. I have tried to bring the knowledge of audiology into the hearing aid field and utilize audiological knowledge as well as we can at the present state of the art. I do not consider this the final ultimate fitting procedure but I expect that improvements will be made as we learn more and more about the ear and about the instrumentation which we can use to help it. Many studies currently in progress will contribute to improved fitting and greater understanding at the same time from you and your client's will show us how well we are doing and the direction to take for further improvement. It is my hope that closer and closer liaison among all of those involved in hearing rehabilitation will ultimately lead to the maximum rehabilitation potential of each and every client we see. Thank you for your interest.